

# Efficient utilization of industrial excess heat for carbon capture and district heating



Heat integration options and seasonal effects on capture process design and operation

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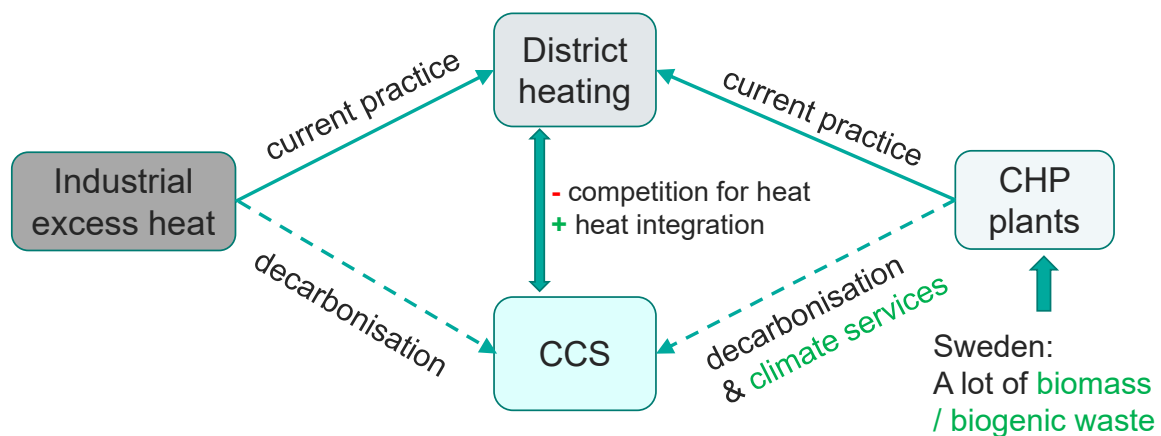
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## CCS versus district heating?



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## Aim & Scope

**Scope:** process industry delivering excess heat to a DH network

- process industry that operates throughout the year
- DH heat demand low during summer
- heat not a main product

**Aim:**

1. Investigate the heat integration potential: how much heat can be recovered from the CCS process and delivered to the DH system?
2. Evaluate CCS operation modes techno-economically: Is seasonally varying load or constant load preferable?



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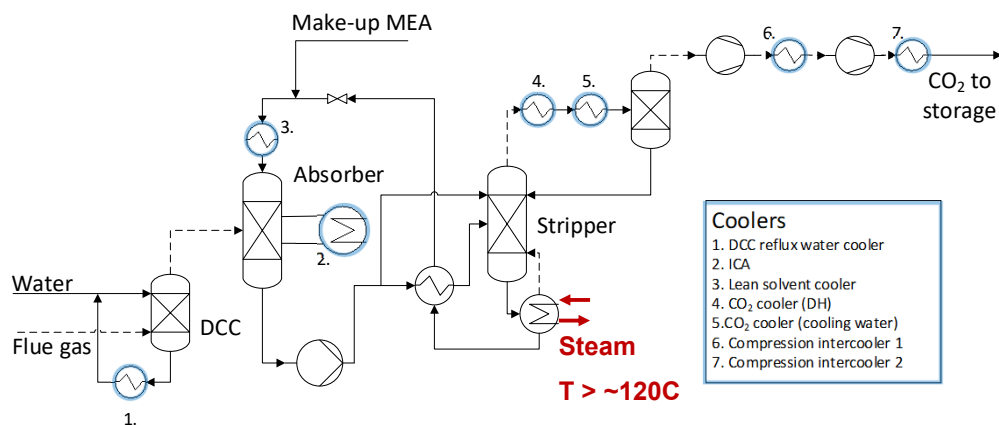
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*how much heat from the CCS process can be recovered and delivered to the DH system?*



## Potential heat sources for DH

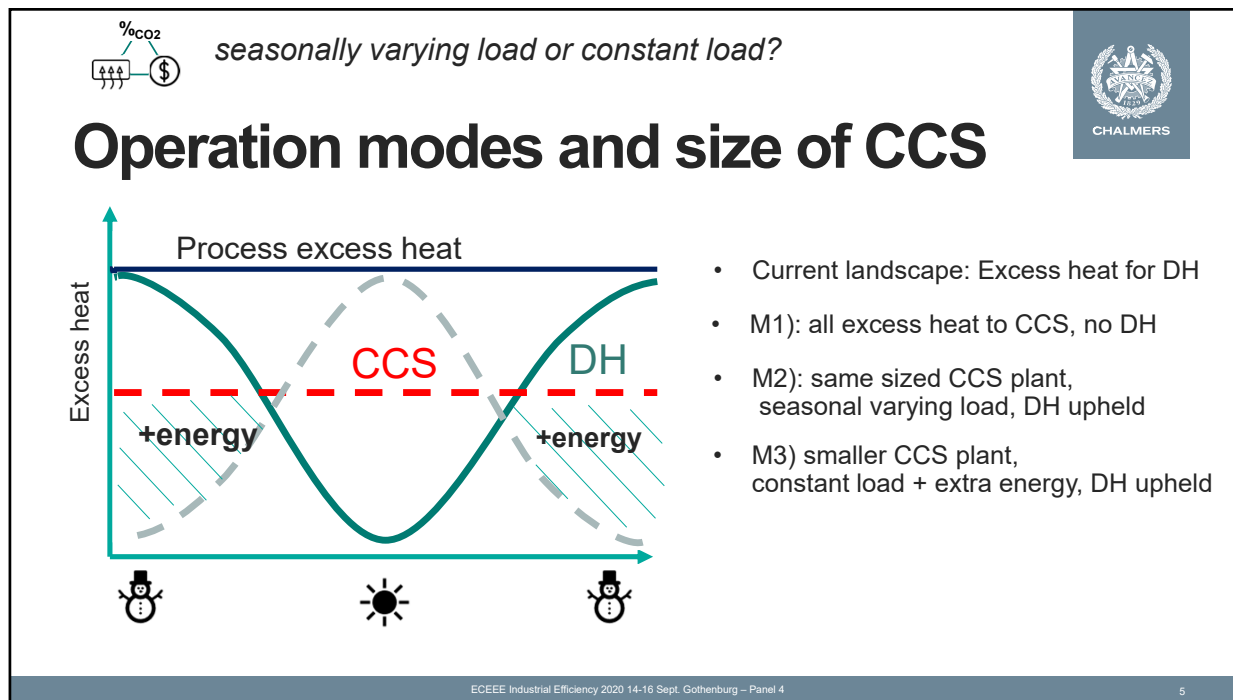


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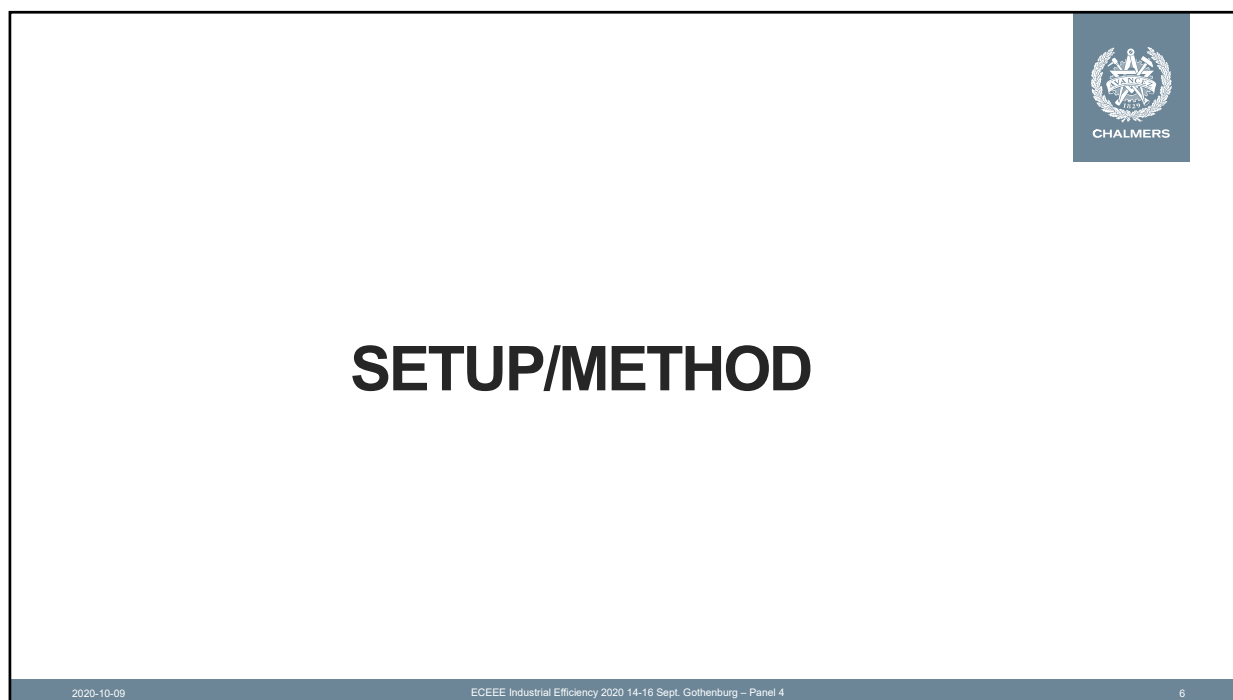
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## Case study setup



	Refinery flue gases	Steelmill blast furnace gas
annual emissions Mt CO <sub>2</sub> p.a.	0.45	1.20
CO <sub>2</sub> concentration [vol.%]	8.9	24.6
DH delivery [GWh/a]	550	850
Heat source	Process heat, heat collection network	Waste-gas fired CHP plant

- maximum available heat for CCS = amount currently delivered to DH
- capture rate = 90%; gas flow varied to scale CCS plant
- CO<sub>2</sub> liquefaction to 7 bar transport pressure;
- DH temperatures 50 – 90 °C

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## RESULTS



*how much heat can be recovered from CCS and delivered to the DH system?*

- Maximize heat supply to CCS;
- DH delivery not maintained; M1

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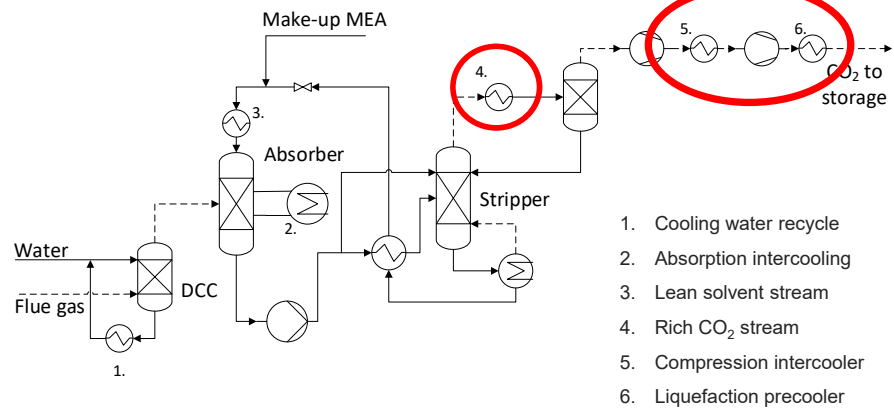
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## CCS process cooling demand



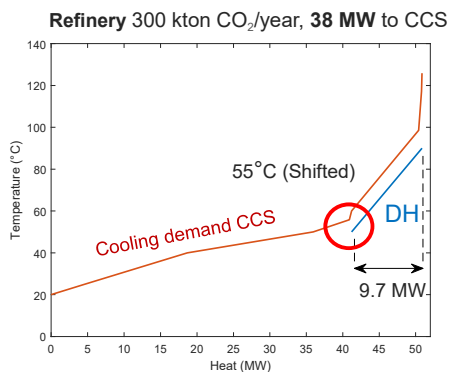
- Minimum temperature difference: 10 °C



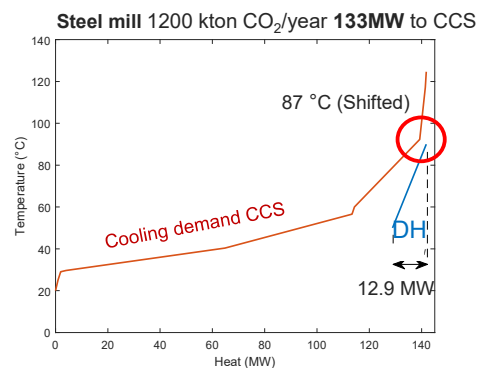
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## Heat recovery potential from the CCS plant to the district heating network



Recoverable heat /  
reboiler duty: 25.5 %



Recoverable heat /  
reboiler duty: 9.7 %

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# OPERATION MODES AND SIZE OF CCS (STEEL MILL EXAMPLE)

*Is seasonally varying load or constant load preferable?*



- DH delivery maintained
- Only excess heat not used in DH is used for CCS; M2 vs M3

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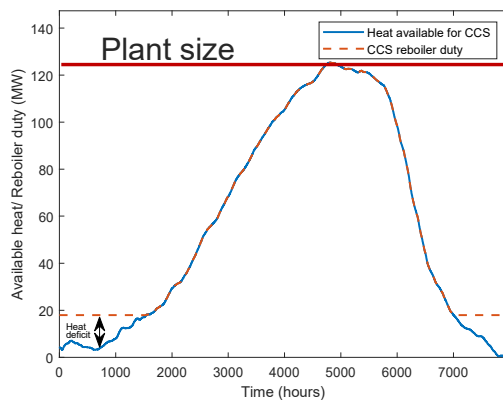
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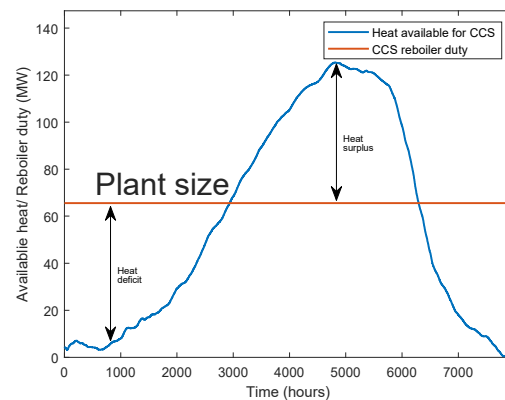
## Varying vs constant CCS load

Seasonally varying load



Minimum load; no shut down

Constant load

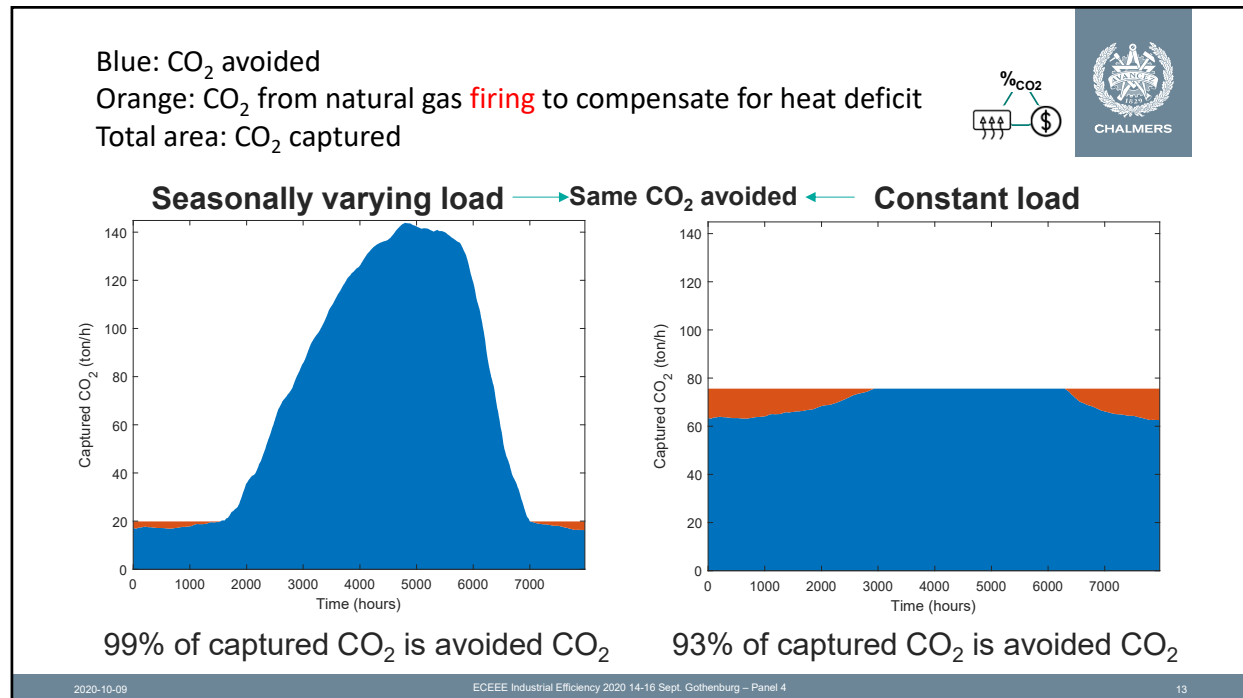


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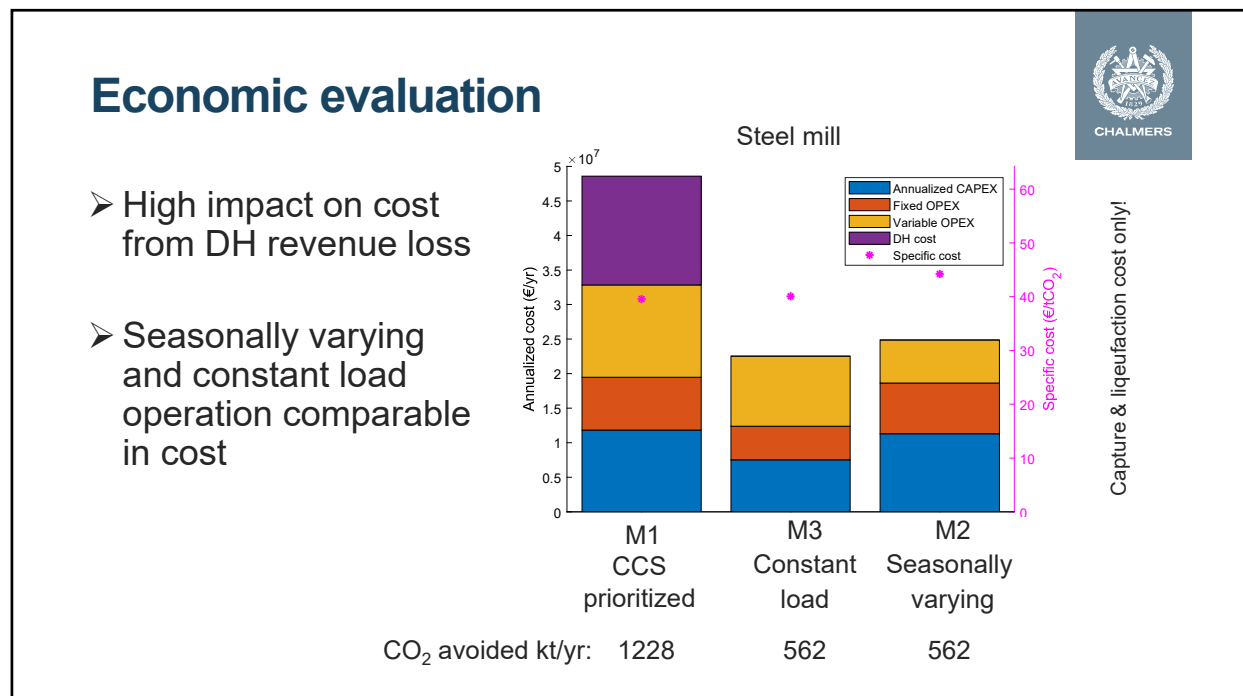
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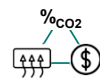
# CONCLUSIONS



- recoverable heat from CCS for DH ~ 10 – 25 % of reboiler duty  
→ depends on  $dT_{min}$ , stripper top gas temperature, process configuration



- Seasonal CCS operation with excess heat has comparable cost (€/t CO<sub>2</sub> avoided) to constant load operation  
→ Highly sensitive towards ratios in energy price (electricity/fuel), scale of the process industry, sizing of the CCS plant, shape of the excess heat load curve



- Seasonal operation uses less primary heat, and allows future scale up of capture (excess capacity due to large CCS plant)
- Revenue loss from decreased delivery of district heat is considerable → for process industry to move away from supplying DH needs to be motivated via emission regulation /funding mechanisms

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## THANK YOU FOR LISTENING!!

### *Relevant publications from our group:*

#### **M.Sc. Thesis report on the topic of this talk:**

Eliasson, Fahrman, 2020. Utilization of Industrial Excess Heat for CO<sub>2</sub> Capture: Effects on Capture Process Design and District Heating Supply <https://hdl.handle.net/20.500.12380/300819>

#### **Power plant flexibility and their products/service:**

J. Beiron, 2020 - *Combined heat and power plant flexibility - Technical and economic potential and system interaction* Licentiate thesis <https://research.chalmers.se/en/publication/516671>

#### **Dynamic performance of CCS plants in process industry:**

Martinez Castilla et al., 2019, Int. J. Greenh. Gas Control 82, 192–203. <https://doi.org/10.1016/j.ijggc.2019.01.015>

#### **Reduction of CCS cost in process industry with partial capture and excess-heat:**

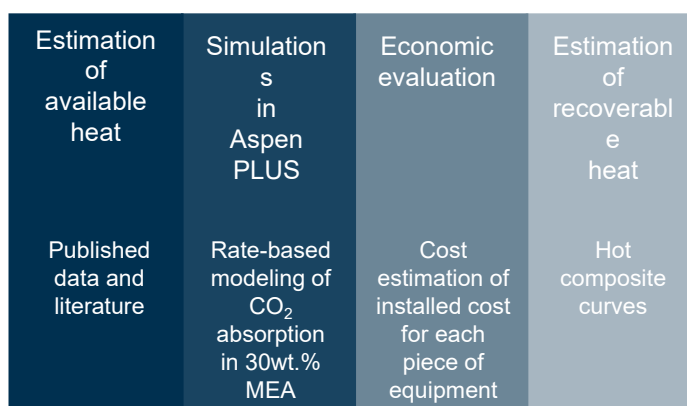
Normann et al. 2019. CO2stCap project report, <https://research.chalmers.se/en/publication/512527>

Biermann 2020 *Partial carbon capture – an opportunity to decarbonize primary steelmaking* Licentiate thesis <https://research.chalmers.se/publication/509851>

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## Methodology



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## METHOD



### Technical modelling of CO<sub>2</sub> capture process

- Aspen Plus rate-based CO<sub>2</sub> absorption model using 30 wt.% MEA <sup>1</sup>
  - Absorber CO<sub>2</sub> separation rate 90%
  - Packing height: 20m absorber, 15 m stripper
  - Lean loading 0.30
  - Compressors in liquefaction plant: 20 bar (2 stage)

### CAPEX estimations

- Equipment cost from cost functions derived from detailed cost literature
- Liquefaction cost scaled from Deng et al. <sup>2</sup>
- Total plant cost estimation with enhanced-detailed factor method <sup>3</sup>
- Individual cost factor for each piece of equipment <sup>3</sup>
- No transport and storage cost considered

### OPEX included:

- Electricity price profiles (Sweden)
- District heat price profiles (marginal system cost)
- Cooling water, amine solvent, maintenance, labor, steam supply cost,

<sup>1</sup> Gardarsdóttir et al., Ind. Eng. Chem. Res. 54, 681–690, 2015

<sup>2</sup> Deng et al., Int. J. Refrig. 103, 301–315, 2019

<sup>3</sup> Ali et al., Int. J. Greenh. Gas Control 88, 10–23, 2019

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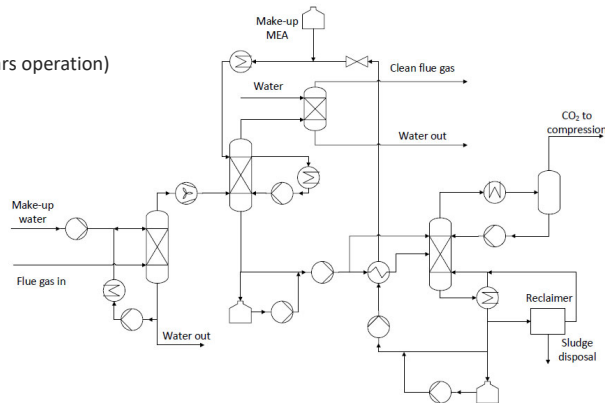
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# COST SCOPE



Equipment included:

Plant life time 25 years (2 years construction, and 23 years operation)  
 Cost year 2016  
 Discount rate 7.5 %  
 First-of-a-kind or N:th-of-a-kind N:th-of-a-kind  
 Greenfield or brownfield Brownfield  
 Location Rotterdam (Location factor 1)  
 Currency conversion factor (€ to NOK 2016) 9.7 NOK/€  
 Material flue gas fan CS ( $f_{mat}$  1)  
 Material pumps SS316 Machine ( $f_{mat}$  1.3)  
 Material other equipment SS316 Welded ( $f_{mat}$  1.75)



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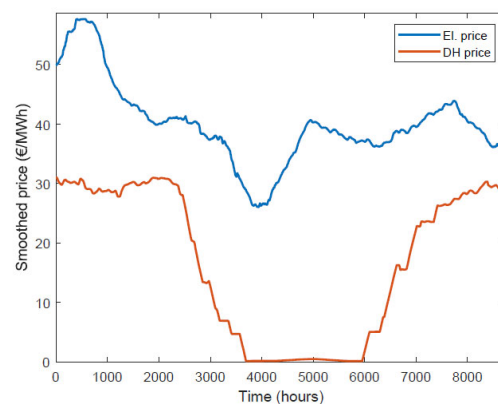
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# OPEX



<b>Fixed OPEX</b>	
Maintenance, insurance and labor cost	6% of TIC
<b>Variable OPEX</b>	
Electricity price	Varying
Average electricity price	40 €/MWh
DH price	Varying
Cooling water price	0.02 €/m <sup>3</sup>
MEA price (including sludge disposal)	2000 €/m <sup>3</sup>
Steam price, steel mill case	1 €/t
Steam price, refinery case	3 €/t
Natural gas price	16 €/MWh
NaOH price	270 €/t



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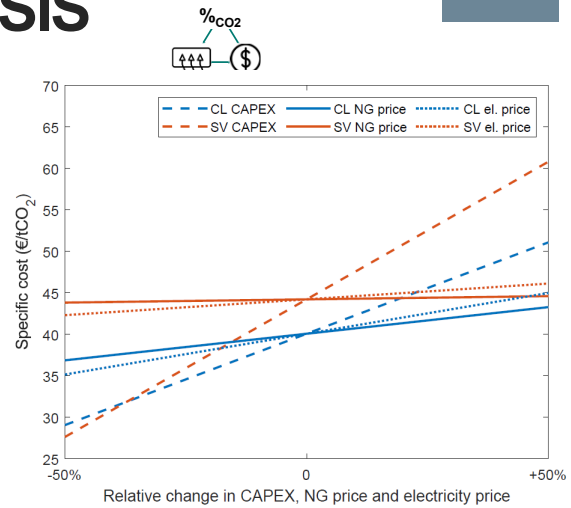
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# SENSITIVITY ANALYSIS

Seasonal varying = red

Constant load = blue

Parameter	-50%	0	+50%
Absolute CAPEX (M€), SV	61.1	122.2	183.3
Absolute CAPEX (M€), CL	40.6	81.1	121.7
Average electricity price (€/MWh)	20	40	60
NG price (€/MWh)	8	16	24



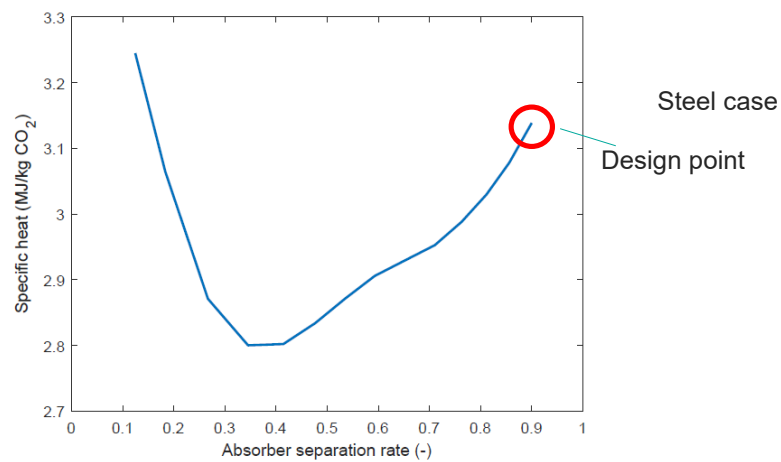
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## Off-design performance

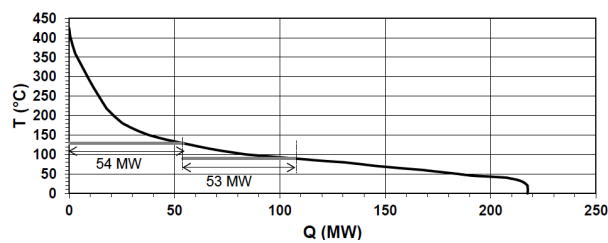


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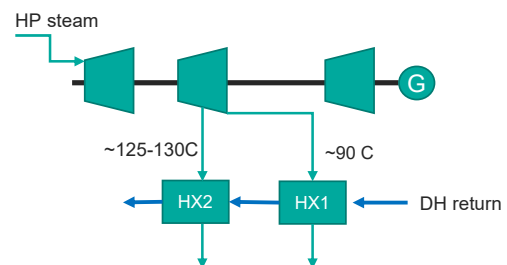
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## Heat supply – excess heat



Refinery: Heat collection network



Steel mill CHP: turbine bleed steam; power generation loss

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